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DETECTION OF CHANGES IN EVAPOTRANSPIRATION ON A CATCHMENT SCALE UNDER CHANGING CLIMATE CONDITIONS IN SELECTED RIVER BASINS OF SLOVAKIA

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Abstract

Potential changes in a hydrological regime caused by a changing climate represent a crucial source of uncertainty in water resources management. For example, in Slovakia, they may manifest themselves in a decrease in water resources, a change in the seasonality of runoff, and an increase in the extremes of floods and droughts. The research presented here focuses on using the hydrological balance equation to predict changes in the total catchment evapotranspiration under changing climate conditions. Using the TUW rainfall-runoff model and the KNMI and MPI climate change scenarios, the hydrological regime of eight selected basins in Slovakia was simulated for three thirty-year periods from 2010 until the year 2100. The results showed that the growth of total catchment evapotranspiration observed in recent decades is likely to increase further in the future.

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Key words

- Evapotranspiration,
- Hydrological balance,
- Seasonality,
- Climate changes.

1 INTRODUCTION

It is generally accepted that human activity has affected the Earth’s climate and, thus, the global hydrological cycle. However, the strong natural variability of climates makes it difficult to estimate the human contribution to changes in the hydrological cycle on the catchment scale. The trends observed in the behaviour of various hydrological elements are not always significant statistically and therefor conclusive. On a local scale, more rain and less snow is expected in mountainous areas in a warmer climate. Anthropogenic warming also increases the water capacity of the atmosphere with consequences for increased evaporation and evapotranspiration over oceans and land, which can cause more extreme precipitation and increase the share of total annual precipitation. Randomly occurring extreme and other deviations from regional trends make the detection and attribution of changes even more difficult.

However, since all components of the hydrological cycle are directly or indirectly affected by rising air temperatures, this must also be reflected in the hydrological balance of a basin. Studying the relationship of the balance provides insight into the complex system of processes that operate in space and over time during the movement of water in nature through the soil, vegetation and the atmosphere. From the point of view of the hydrological balance, a changed precipitation regime can have both favourable and unfavourable effects on the replenishment of underground water supplies. Monitoring and predicting changes in the long-term regime of the key elements of the hydrological balance on a basin scale is, therefore, urgent. Through analyzing the balance, the indirect detection of changes in particular hydrological elements is also possible.

When computing a hydrological balance, it is crucial to integrate data on the hydrological cycle into a consistent set of figures, which must adequately represent the processes that must be considered on the given temporal and spatial scales. Integrating datasets from different sources requires a careful selection of the available data products of each variable, taking into account the appropriate spatial and temporal resolutions (Dorigo et al., 2021). The data selection determines whether and how the closure of the hydrological balance is ultimately achieved. Ideally, consistency between the selected data products would already be taken into account at the acquisition stage (Popp et al., 2020), but this is generally impossible due to the diversity of monitoring programs for the different components of the water cycle. Problematic elements include, for example, total evaporation from the catchment estimated by modelling or by analogy, estimates of the flow in unmeasured basins, or withdrawals from reservoirs estimated from observing changes in water levels (Pellet et al., 2019). Determining the values of total evapotranspiration and subsurface runoff is especially problematic. Using the example of the balance of 63 basins of the Amazon River, Posada and Poveda (2020) discussed the reasons for not closing the balance due to nonstationarity, which can make it difficult. From the point of view of the integration of the data from different sources, we can say that the larger the scales, the lower the uncertainty of determining the individual balance inputs due to the averaging of the data (Rodell et al., 2015). For example, when considering the hydrological balance of a basin over several decades, we can deal with the long-term average values of the inputs and ignore changes in all the forms of water accumulation in the basin. However, due to the difficulty of measuring evapotranspiration (ET) and the inaccuracy of estimating total rainfall in a catchment, the factors affecting changes in ET are the subject of research and debate (Duethmann and Blöschl, 2018). Territorial evapotranspiration values cannot be measured directly; the only possibility is assessing them indirectly.

A robust and straightforward option for estimating territorial evaporation is evaluating the hydrological balance equation on the basin level, especially when calculating its long-term average (Duethmann and Blöschl, 2018). Estimates of the evapotranspiration itself can be based on experimental on-site micrometeorological assessments (e.g., evaporimeters and lysimeters) (Hobbins et al., 2004), spatial estimates using remote sensing methods (Zhang et al., 2010; Gao et al., 2010), and outputs from rainfall-runoff models (e.g., Parajka et al., 2004; Huang et al., 2020). In addition, we can use spatial interpolation methods from empirical point estimates of actual evapotranspiration performed in a large number of ways of varying complexity (Hobbins et al., 2001; Lapin et al., 2016). Hydrological mapping can also estimate their values (e.g., Parajka et al., 2004). As a result of the above-mentioned problems, it is clear that if we accept the assumption of closure of the balance, the estimate of ET will contain the uncertainties mentioned above (Fekete et al., 2004; Wang et al., 2014 a, b). However, for practical reasons, we cannot consider this as a reason for cancelling the use of balance in hydrology (Safeeq et al., 2012). Therefore, to use the hydrological balance as a method for changes in the hydrological regime in a period of a changing climate, we can say that it is appropriate to try to use it on the scale of basins, with an annual time step, and for a sufficiently long period (on the order of decades).

Many studies have reported that evapotranspiration has regionally increased in many parts of the world in recent decades (Zhang et al., 2010). Investigations of trends in catchment evapotranspiration through the hydrological balance have generally noted an increase in recent decades (Domokos and Sass, 1990; Mills, 2001; Weingartner et al., 2007; Trenberth et al., 2007). A global study found positive (but only sometimes significant) trends in North and South America and Europe and negative trends in Africa and Siberia (Ukkola and Prentice, 2013). Many studies have been devoted to the river basins of North America (Milly and Dunne, 2001; Walter et al., 2004; Gao et al., 2010; Kramer et al., 2015; Xiao et al., 2020). National assessments have also been published (Mills, 2001; Weingartner et al., 2007; Duethmann and Blöschl, 2018; Mastrotheodoros et al., 2020; Xiao et al., 2020; Tomas-Burguera et al., 2021). Several results of the assessment of changes in the elements of the hydrological cycle in Slovakia also indicate that their regime has recently changed (e.g., Blaškovičová et al., 2019; Fendeková et al., 2018). Consistent trends regarding their development have been found, and some of these were significant (e.g., Lapin et al., 2016; Pramuk et al., 2016; Ďurigová et al., 2019; Halmová et al., 2019; Ďurigová, 2020). Overall, more work has been devoted to looking for trends in time series of the elements of the hydrological balance and changes in their regime than comparing changes in the overall balance. Impacts due to climate change concerning the general hydrological balance have been rare.

Rončák and Šurda (2019) and Rončák et al. (2019) have dealt with estimating the components of the water balance under a changing climate in selected basins of Slovakia. Using the spatially distributed WetSpa model, the KNMI and MPI regional climate models, and the SRES emission scenario for future estimates have shown an increase in the current evapotranspiration and a decrease in soil moisture in future horizons compared to the reference period of 1981-2010. Csáki et al. (2020) has developed a long-term climate-runoff model. Long-term evapotranspiration and runoff values have been projected for three periods (2011–2040, 2041–2070, 2071–2100) over the Zala River Basin in Hungary, using data of 12 regional climate models. According to the projections, by the end of the century, the annual evapotranspiration rate is expected to increase by 4-5% relative to the reference period (1981–2010).

In this study, we primarily focused on evaluating the equation of the hydrological balance in eight pilot catchments in Slovakia under changing climate conditions. The work does not aim at developing or testing new modelling procedures. The main goal is to gain new knowledge about the possible impacts of climate change on the hydrological balance using a series of published data in Sleziak et al. (2021).

2 MATERIAL AND METHODS

2.1 Pilot basins and data

The study herein follows up on Sleziak et al. (2021), from which we have adopted the climate and runoff data. We have selected eight watersheds as pilots (see Fig. 1). All the chosen basins lack anthropogenic influences. They cover the territory of Slovakia in a transect from west to east and represent different altitudinal zones. The basin sizes proved suitable for using a conceptual rainfall-runoff model with a daily step. Tab. 1 summarizes the main basin characteristics. The dimensions of the basins range from 238 km^2 (Myjava - Jablonica) to 2094 km^2 (Nitra - Nitrianska Streda); the mean elevations vary from 362 m a.s.l. (Myjava - Jablonica) to 1090 m a.s.l. (Váh - Liptovský Mikuláš). Using the inverse distance weighting method, precipitation from the individual climate stations was aggregated into average precipitation totals for the basins. The average daily air temperatures per watershed were calculated using the gradient method for the median elevation of the watershed. The average daily potential evapotranspiration per watershed was calculated by a modified Blaney–Criddle method.

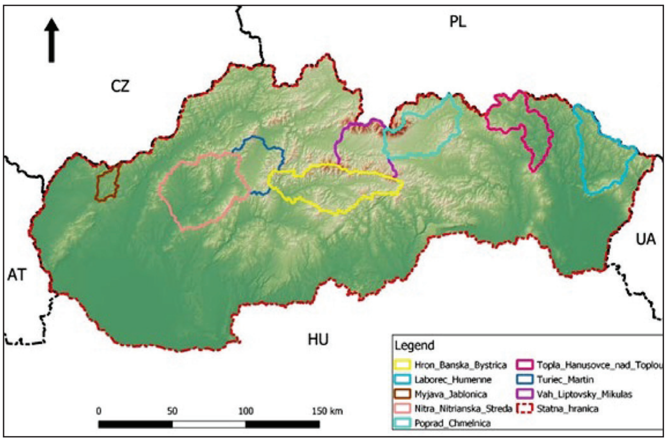

Fig. 1 *Topography of Slovakia and locations of the eight river basins selected*

Tab. 1 *Basic characteristics of the selected pilot catchments of Slovakia*

ID	Gauging station	River	Catchment area	Mean elevation
			[km^2]	[m a.s.l.]
5022	Jablonica (J)	Myjava	238.5	361.7
6730	Nitrianska Streda (NS)	Nitra	2093.7	419.5
9230	Humenné (H)	Laborec	1272.4	421.7
9500	Hanušovce nad Topľou (HnT)	Topľa	1050.0	435.4
6130	Martin (M)	Turiec	827.0	716.0
7160	Banská Bystrica (BB)	Hron	1766.5	844.4
8320	Chmeľnica (Ch)	Poprad	1262.0	878.1
5550	Liptovský Mikuláš (LM)	Váh	1107.2	1090.1

The data input (i.e., the mean daily air temperatures and daily precipitation totals) for the modelling of runoff in the period 2010 to 2100 were generated by two regional circulation models (RCMs). The Koninklijk Nederlands Meteorologisch Instituut (KNMI) and Max Planck Institute (MPI) models are based on the German ECHAM5 general circulation model (GCM) boundary conditions and represent a detailed integration of the atmospheric and oceanic dynamic equations with a grid point resolution of roughly 25 × 25 km (Lapin et al., 2012).

In impact studies conducted in Slovakia, the moderately pessimistic SRES A1B emission scenario is usually adopted. This emission scenario is between the SRES B1 (relatively low emission of greenhouse gases) and A2 (a rather high emission of greenhouse gases) scenarios (Minďáš et al., 2015). Outputs from both RCMs were downscaled into a network of climate stations (Lapin et al., 2012). Details are given in Fendeková et al. (2018). The outputs from both climate models for the basins studied were downscaled to the climatic stations and interpolated using the Inverse Distance Weighted (IDW) and altitude gradient methods on the basin's data. The values of the mean daily air temperatures and daily precipitation totals were used as the daily basin average data for the period between 2011 and 2100.

The data from Sleziak et al. (2021) contain the simulated runoff for the reference period (1981-2010) in a daily time step from eight basins in Slovakia and for three thirty-year periods from 2010 until 2100 (2011-2040, 2041-2070, 2071-2100). To simulate runoff driven by precipitation from the KNMI and MPI regional climate models in the Slovak basins selected, the conceptual rainfall-runoff (r-r) TUW model was chosen. The TUW model is a lumped model based on the structure of the widely used Swedish Hydrologiska Byrans Vattenbalansavdelning (HBV) model. The model has recently been proven to be suitable for analyses of the impact of climate change on water resources in several studies concerning Slovakia (e.g., Sleziak et al.,2016; Sleziak et al., 2018; Aleksić et al., 2021).

Sleziak et al. (2021) described three thirty-year periods (2011-2040, 2041-2070, and 2071-2100) separately and in detail for each pilot river basin. Changes in the long-term mean monthly climatic characteristics (air temperature and precipitation) according to both climate models are expected to be similar for each river basin. An increase in precipitation can be expected during the spring, autumn, and winter periods. Precipitation is expected to decrease in the summer. Based on the KNMI model, the largest increase in precipitation is expected to be in September (2071-2100). Interestingly, the maximum of the long-term mean monthly precipitation could be shifted from July to September in all three future periods. The MPI model predicts the largest precipitation increase to be in March for the period 2071-2100. The long-term mean monthly air temperatures will rise steadily according to both scenarios.

2.2 Methodology

Total evapotranspiration in a catchment's hydrological balance is the total amount of water in all its forms that evaporates from the catchment over a specified period of time. Several synonyms, such as actual evapotranspiration, climatic evaporation, territorial evaporation, and total evaporation are used (Keszeliová et al., 2021). Both "actual catchment evapotranspiration" and a total catchment or a basin evapotranspiration will be used herein.

The relationship between the volumes of water entering and leaving the area of a catchment during a given time interval Δt can be described as a conservation of mass by (e.g., Keszeliová et al., 2021):

$$Z + K + P_P + P_R + P_{PZ} = O_P + O_{PZ} + O_O + V + \Delta R \quad (1)$$

where the individual symbols represent the following volumetric quantities:

Z – vertical precipitation,
K – horizontal precipitation (e.g., condensation of water vapour),
P_P – the natural influx of water on a surface into a catchment,
P_R – the anthropogenic transfer of water into a catchment,
P_{ZP} – the natural groundwater inflow into a catchment,
O_P – the natural surface outflow of water from the catchment,
O_{PZ} – a natural underground outflow from a catchment,

O_O – abstractions of the surface and groundwater transferred outside the catchment,
V – the total evaporation of water from the territory (actual catchment evapotranspiration), which includes all forms of water evaporation and plant transpiration),
ΔR – change in the water storage in the catchment over the time interval Δt considered.

The values of the variables of the balance equation can be expressed in volumetric units or units of depth for the given catchment (precipitation depth, runoff depth).

When assessing the hydrological balance of natural catchments (without any anthropogenic effect on the budget) over a sufficiently extended period to ignore any change in storage, the equation may be simplified as:

$$Z = O + V \qquad /\Delta t \tag{2}$$

where: Z, O, and V are the atmospheric precipitation, runoff, and actual catchment evapotranspiration, respectively; and Δt is a relatively long period of time (Duethmann and Blöschl, 2018). By dividing both sides of the equation by the duration of the period under review (Δt), we can express its terms as the long-term average values of the river basin's atmospheric precipitation, runoff, and actual evapotranspiration (e.g., Keszeliová et al., 2021).

As a central part of this case study, we are addressing the question of how climate change may affect the hydrological balance. To analyze changes in the behaviour of the elements of a balance, the linear trends of its components in the eight pilot basins were evaluated. We have tested the acceptance of the trends observed by the standard Mann-Kendall test (e.g., Ďurigová et al., 2019). We have used the calendar year as the basis of the balance.

The TUW rainfall-runoff model, which produced the data analyzed herein, uses the inputs of the average basin values of the mean daily air temperatures, daily precipitation totals, and potential evapotranspiration. The model has 15 parameters that need to be calibrated. The evolution strategy, known as differential evolution (Mullen et al., 2011; Ardia et al., 2016), was used for the parameter optimization. It is considered successful in finding the global optimum of a real-valued function of real-valued parameters and does not need continuous or differentiable objective functions.

In Sleziak et al. (2021), the model was calibrated/validated consecutively for four 10-year periods between 1981-2019. The objective function for the runoff was the average of the Nash-Sutcliffe coefficient (NSE), and the logarithmic NSE (Nash and Sutcliffe, 1970) was applied. For simulating the future runoff conditions, parameters from the most recent calibration period (i.e., 2011-2019) were selected because it was assumed that this period should be similar (mainly in terms of the mean daily air temperatures) to a recent/warmer climate.

As seen in Fig. 2 below, it was decided that it was more acceptable to choose a period that could be similar in temperature to a future (i.e., warmer) climate. This consideration was also supported by a comparison of selected quality indicators of model simulations during the cross-validation in the periods 1981-1990, 1991-2000, 2001-2010, and 2011-2019.

3 RESULTS

A comparison of the development of the hydrological balance in the coming decades for both scenarios simultaneously and separately for the individual pilot basins is presented; they are sorted according to their average elevation. In addition, we have compared changes in the long-term averages of the main elements of the hydrological balance between the simulated reference (baseline) period of 1981-2010 and the projection periods of both scenarios in Figs. 3, 4, and 5. An assessment of the direction and significance of the trends of the elements of the hydrological balance is also presented.

Due to the uncertainties associated with the scenarios and the rainfall-runoff modelling, it is not appropriate to describe the outputs from the projections for the individual basins in detail. Instead, it is more relevant to evaluate the overall picture of the possible changes expected in the long-term hydrological balance for particular periods and the directions of the differences between them and within them.

The most important finding is that the future predictions are practically the same for both scenarios. Both projections do not assume significant changes in the overall hydrological balance compared to the baseline. It is essential that these scenarios allow for an increase in precipitation. The rising air

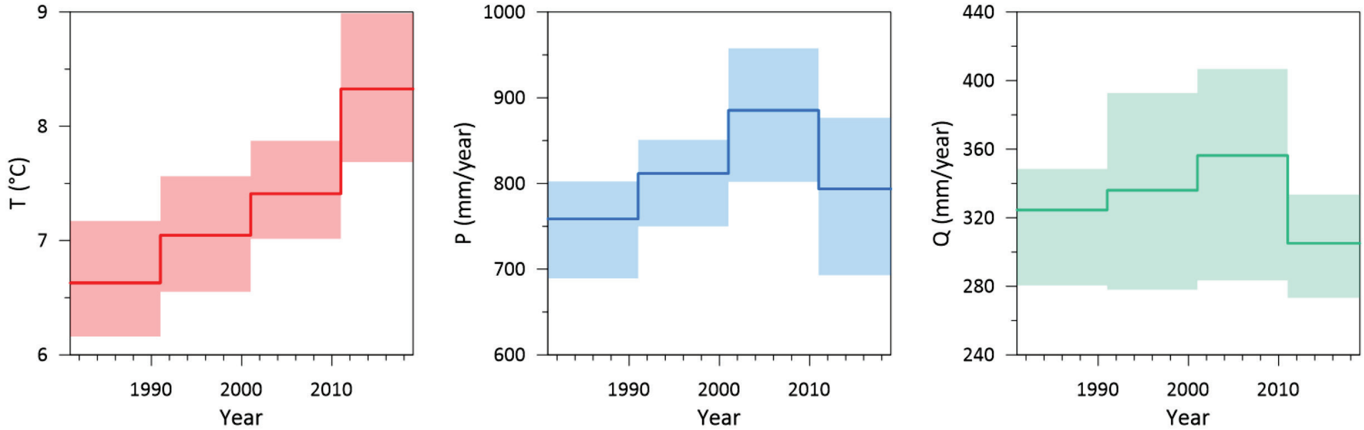

Fig. 2 *Changes in the hydroclimatic characteristics (long-term mean annual precipitation - P, air temperature - T, and runoff - Q) over four decades. The line represents the medians of these characteristics for each of the four periods (i.e., 1981-1990, 1991-2000, 2001-2010, and 2011-2019) for the eight river basins. The scatter (i.e., the 75th and 25th percentiles) indicates the variability between the basins.*

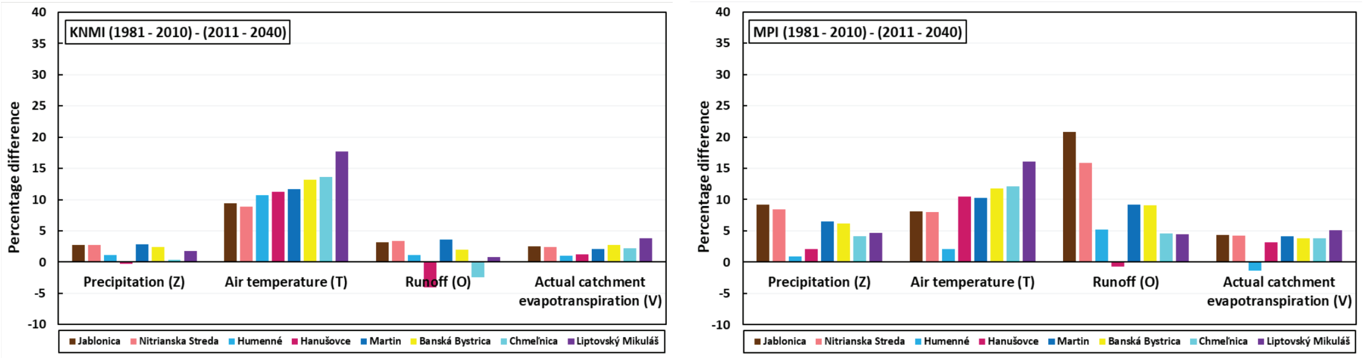

Fig. 3 *Comparison of changes in the values of elements of the hydrological balance for both scenarios (KNMI and MPI) in the pilot basins for 2011-2040 compared to the baseline period*

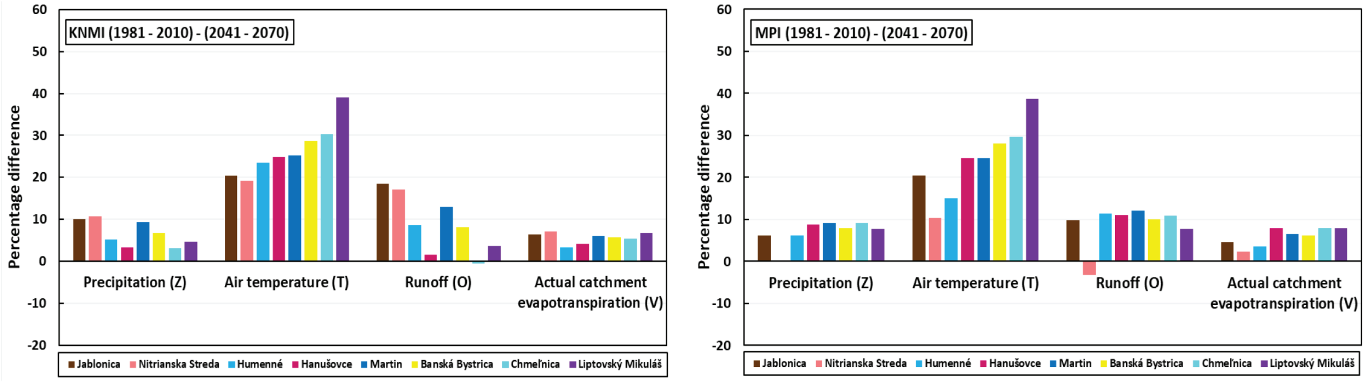

Fig. 4 *Comparison of changes in the values of the elements of the hydrological balance for both scenarios (KNMI and MPI) in the pilot basins for 2041-2070 compared to the baseline period*

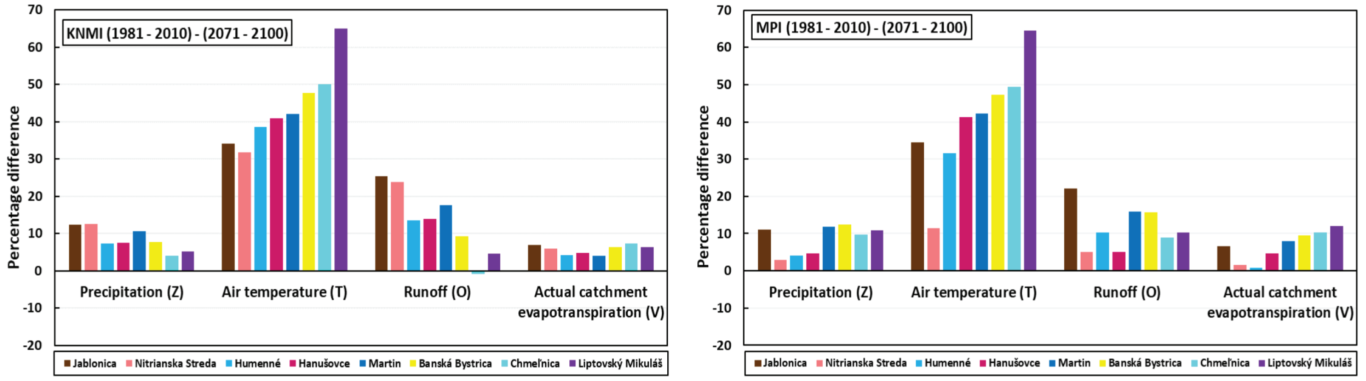

Fig. 5 *Comparison of changes in the values of the elements of the hydrological balance for both scenarios (KNMI and MPI) in the pilot basins for 2071-2100 compared to the baseline period*

temperature, which is not disputed, increases the territorial evaporation, but the increase in precipitation also enables the growth of the (long-term) average annual runoff. However, in this respect, it should be considered that both scenarios are based on the boundary conditions of the German ECHAM5 global circulation model.

The expected development of the long-term hydrological balance can be divided into two spatially divided groups of basins. These differ according to the share of runoff and territorial evapotranspiration based on the precipitation and in their vertical zonality. This division appears to the be same in both scenarios, as indicated in Figs. 6, 7, and 8.

The Myjava - Jablonica, Nitra – Nitrianska Streda, Turiec – Martin, and Váh – Liptovský Mikuláš basins show an increase

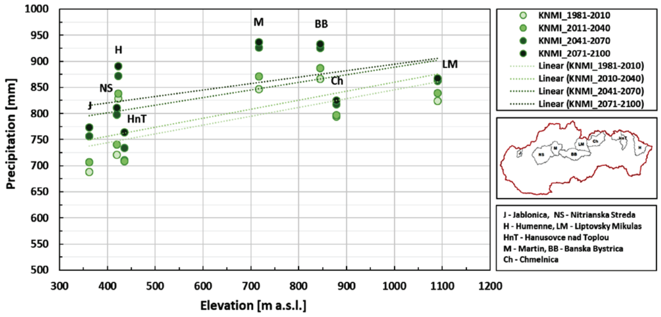

Fig. 6 *Analysis of the vertical zonality of the long-term averages of the precipitation totals in the pilot basins in relation to the average altitude of the pilot basins*

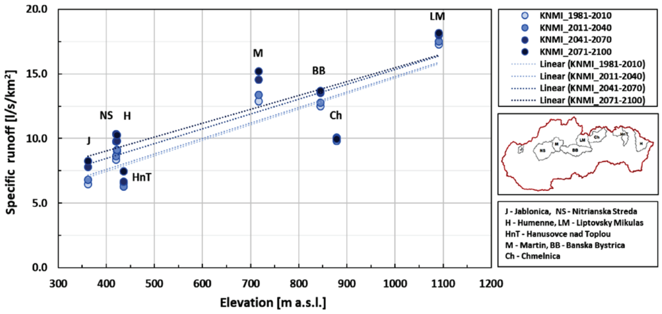

Fig. 7 *Relationship between the long-term average annual specific runoff and the average elevation of the pilot watersheds*

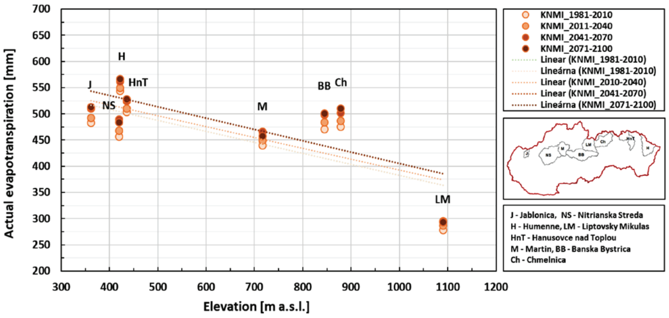

Fig. 8 *Relationship between long-term average annual actual catchment evapotranspiration and the average elevation of pilot watersheds*

in runoff and a decrease in territorial evaporation with increased altitudes. This is the same tendency that the basins on the western side of the Carpathian arc indicated in Keszeliová et al. (2021). The second group is formed by the catchments of Laborec - Humenné, Topľa – Hanušovce nad Topľou (east), Hron – Banská Bystrica, and Poprad – Chmeľnica (centre). The vertical zonality is preserved between the basins in the east and the centre but is not manifested within the regions.

When evaluating the trends of the hydrological balance components in the individual basins, we must remember that, over the long term, trends from thirty years cannot be considered representative. Here, we have mainly evaluated them by looking at an assessment of their significance (using the Mann-Kendall test at the 95 % level of significance). Tab. 2 contains an evaluative summary of the trends and their significance in the Váh catchment up to Liptovský Mikuláš for the baseline period (1981-2010) and all three thirty-year periods (2011–2040, 2041–2070, 2071–2100). Other basins were analyzed with the same approach too.

From this point of view, the "insignificant" evaluation prevails in Myjava - Jablonica, Laborec - Humenné, Hron – Banská Bystrica and Váh – Liptovský Mikuláš. On the other hand, significance prevails in the basins of Nitra – Nitrianska Streda and Topľa – Hanušovce nad Topľou, and there is a mixed picture in the basins of Poprad – Chmelnica and Turiec - Martin. As for the direction, we indicate that an increase in the range of average annual values prevails.

From a detailed analysis of the results of this study in an individual calendar month, the nature of the intra-annual distribution of the runoff does not differ from the results of similar studies in the Slovak Republic; the latest results were published by Sleziak et al. (2021) for the same set of basins using the same data. The general picture can be characterized relatively simply. The runoff increases at the beginning of the calendar year compared to the baseline scenario (the first two to four months). A similar picture occurs towards the end of the year, but the increase is not so significant (two to three months), and the flow is generally lower. In the rest of the year, a decrease in monthly flows can be expected compared to the baseline scenario. The difference between the rainfall and runoff shows a mirroring image of the fluctuations. However, when looking at the long-term balance, the two scenarios only signal a redistribution in the seasonality of the monthly flows. The overall balance does not deteriorate. Moreover, even an increase in the annual runoff (and total evapotranspiration) through all three periods in the future is possible.

4 DISCUSSION

Impact studies are inherently burdened by a cascade of uncertainties inherent in all steps of assessing the impact of climate change on runoff using hydrological modelling (e.g., Dankers and Kundzewicz, 2020), and their impact is linked. In the beginning, the uncertainties are inherent in the climate scenarios and their downscaling; the problems associated with determining the inputs and parameterising the rainfall-runoff models follow. To better quantify the uncertainties in the modelling chain, several authors have proposed to compare regional outputs from multi-scenario systematically and from multi-modelling simulations (Vetter et al., 2015; Hattermann et al., 2017, 2018; Krysanova and Hattermann, 2017; Krysanova et al., 2016, 2017). In our country, such approaches are still lacking.

Tab. 2 *Trends (positive – arrow up, negative - arrow down) and their statistical significance (YES or NO) at the 95 % level from the Mann-Kendall test in the series of the areal averages of the components of the hydrological balance (precipitation, air temperatures, runoff, actual catchment evapotranspiration) in the Váh catchment up to Liptovský Mikuláš for the baseline period (1981-2010) and all three periods in the future (2011–2040, 2041–2070, 2071–2100)*

Scenarios	Periods				Component of the hydrological balance
	1981-2010	2011-2040	2041-2070	2071-2100	
KNMI	↑ NO	↑ NO	↑ NO	↓ NO	Precipitation (Z)
	↓ NO	↑ YES	↑ YES	↑ YES	Air temperature (T)
	↑ NO	↓ NO	↑ NO	↓ NO	Runoff (O)
	↑ NO	↑ NO	↑ NO	↓ NO	Actual evapotranspiration (V)
MPI	↑ NO	↑ NO	↑ NO	↓ NO	Precipitation (Z)
	↑ NO	↑ YES	↑ NO	↑ YES	Air temperature (T)
	↑ NO	↑ NO	↑ NO	↓ NO	Runoff (O)
	↑ NO	↑ NO	↓ NO	↑ NO	Actual evapotranspiration (V)

From this point of view, the study presented has several defects. Regarding the structure and parameterization of the TUW model, we used conceptual rainfall-runoff modelling with a daily step. The use of the conceptual model is adequate because distributed r-r models that have proven themselves elsewhere in the region, such as WASIM and WETSPA, would bring about significant complications with parameterization and its dependence on climate change. The choice of daily steps has also limited the selection of scenarios. Scenario data that are downscaled to precipitation and climate stations with a daily step was necessary. Such data are usually not available from the available RCMs for the territory of Slovakia. There is a deficit in multi-emission and multi-RCM climate scenarios downscaled to the individual climate stations in Slovakia. To cope with the problem, regional climate models were selected with expert assistance in cooperation with specialists from the National Climate Program. The same applies to the SRES emission scenario. In doing so, the scope for evaluating the uncertainties of the outputs were consciously narrowed (but this applies to most imported studies from the recent past in the Slovak Republic). On the other hand, the selected models and the emission scenarios are considered to reproduce the climate of Slovakia's instrumental period adequately and were almost exclusively applied in the recent past in impact studies (e.g., Fendeková et al., 2018). However, the fact that new types of RCP emission scenarios are insufficiently applied in Slovakia could not be resolved.

Uncertainties associated with modelling runoff with conceptual models have long been known and discussed in the literature (e.g., Uhlenbrook et al., 1999). Methodological progress has been directed towards verifying and quantifying uncertainties caused by the models' structures and parameterization. Here, we avoided the complexity of such a solution by assuming that a model calibrated in a warmer period from the recent past could be sufficiently characteristic of the climate conditions in the future. The study from which the runoff modelling results were used (Sleziak et al., 2021) analyzed the calibration and cross-validation of the TUW model over several periods and showed that the calibration from the last warm period did not indicate acceptable validation results in less warm periods in the past. A similar conclusion was also valid for the opposite procedure. Therefore, we indirectly assumed that such a calibration would be suitable for a warmer future in our case.

5 CONCLUSIONS

From the point of view of the hydrological balance, the results signal the possibility of a change in the seasonal distribution of runoff. However, the changes in the long-term balance between future periods and the baseline were insignificant. Rather, the overall long-term balance could remain at the current level. In the hydrological balance with an annual step, the shift of the increased runoff to the winter and early spring appearing in our results compensates for the decrease in runoff and the increase in potential evaporation in summer. This is how the projections of both scenarios used appear, which to some extent, could increase the credibility of the findings. These results also support the plausibility of the downscaling and modelling. At the same time, however, they clearly show that since the common denominator of both scenarios is the same emission scenario and the same GCM, it will be necessary to introduce a multi-scenario assessment containing both extremes of the possible development of emissions.

The phenomenon that the overall hydrological balance may not significantly change appears less often in discussions about the impact of climate change on Slovakia's hydrological regime. Therefore, its confirmation or avoidance with a multi-scenario and multi-model approach would be more than necessary. For a viable proposal for climate change adaptation, it is essential to have a more comprehensive selection of emission and climate scenarios and parallel multi-model studies prevent our thinking from always being headed in the same direction.

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